Initial Study of An Effective Fast-time Simulation Platform for Unmanned Aircraft System Traffic Management

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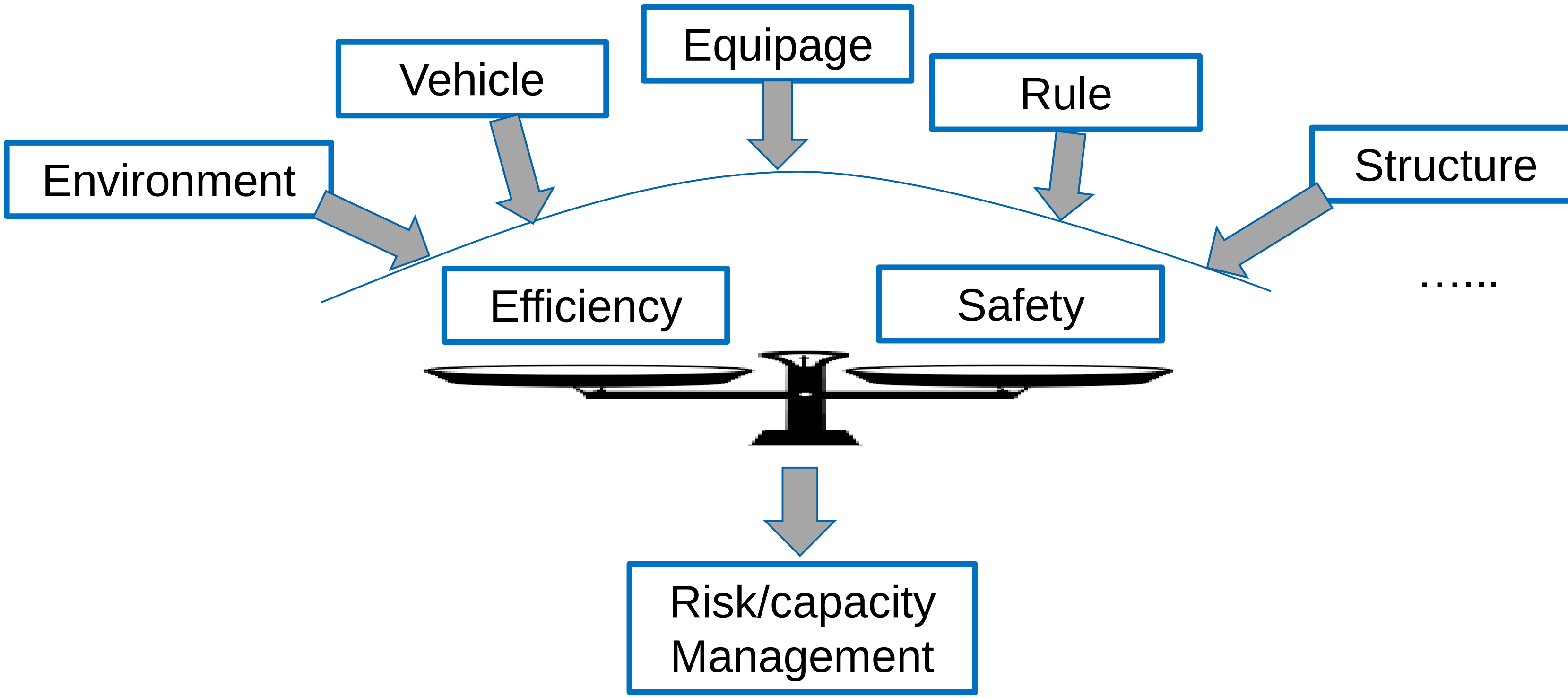
Moffett Field, CA

AIAA Aviation Forum, 5-9 June 2017

Motivation



Objective: Initial study and justification of developing an effective fast-time simulation platform

Outline

- Overview of existing simulations
- Requirements of UTM simulations
- Experiments using UTM simulations
- Summary

Simulation Categories

- Operations (multiple aircraft)
  - Manned aircraft: CTAS, FACET, ACES
  - Small UAV: Jenie[JGCD2016], Cook[AIAA2016]
- Encounter (~two aircraft)
  - MIT Lincoln Lab
  - Mueller[MST2016]
- Vehicle centric (single aircraft)
  - Reflection[NASA-TP2006]
  - Others

Comparison

Simulation	UTM required
Maximum number of vehicles per scenario	>100
Fidelity of vehicle models	>medium
Vehicle’s controller modeled?	✓
Wind effect	Along-track + cross-track + vertical
Limited flight duration?	×
Capability of Monte Carlo simulations?	✓
Collision avoidance algorithm included?	✓

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Small UAV Trajectory Model

Dynamics:

$$\begin{bmatrix} \dot{p}_n \\ \ddot{p}_n \\ \dot{p}_e \\ \ddot{p}_e \\ \ddot{h} \\ \ddot{\phi} \\ \ddot{\theta} \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} \dot{p}_n + \omega_n \\ -(\cos\phi \sin\theta \cos\psi + \sin\phi \sin\psi) F_z/m \\ \dot{p}_e + \omega_e \\ (-\cos\phi \sin\theta \sin\psi + \sin\phi \cos\psi) F_z/m \\ g - \cos\phi \cos\theta\, F_z/m \\ M_\phi / J_x \\ M_\theta / J_y \\ M_\psi / J_z \end{bmatrix}$$

Controller: [proportional-derivative (PD)]

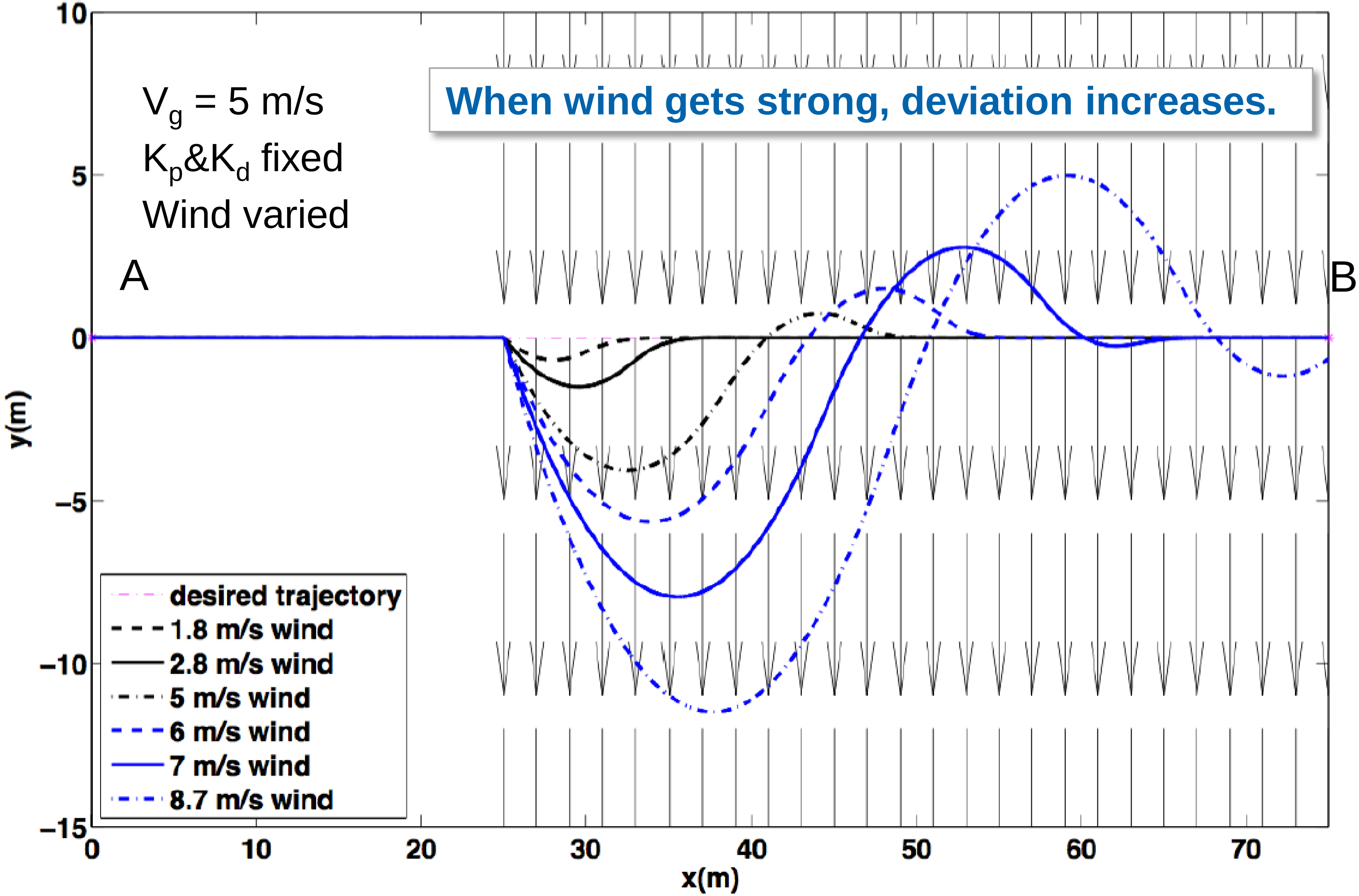
$$\begin{bmatrix} \ddot{p}_e \\ \ddot{p}_n \end{bmatrix} = \begin{bmatrix} k_p\left(p_{e,d} - p_e\right) + k_d(\dot{p}_{e,d} - \dot{p}_e) \\ k_p\left(p_{n,d} - p_n\right) + k_d(\dot{p}_{n,d} - \dot{p}_n) \end{bmatrix}$$

$$\begin{bmatrix} \phi_d \\ \theta_d \end{bmatrix} = \frac{m}{F_z} \begin{bmatrix} -\sin\psi & -\cos\psi \\ \cos\psi & -\sin\psi \end{bmatrix}^{-1} \begin{bmatrix} \ddot{p}_e \\ \ddot{p}_n \end{bmatrix}$$

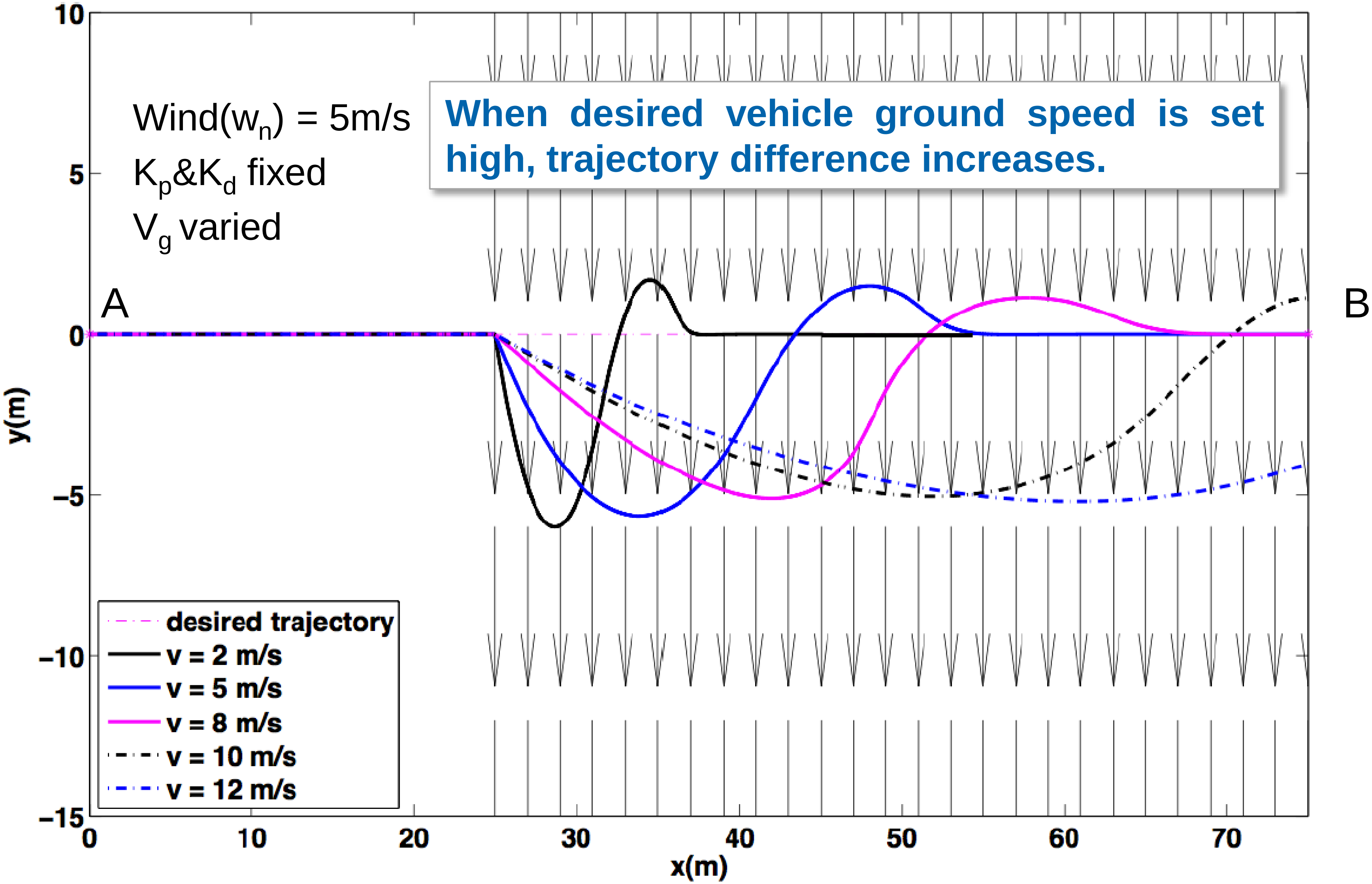
$$\begin{bmatrix} M_\phi \\ M_\theta \end{bmatrix} = \begin{bmatrix} k_{p,\phi}(\phi_d - \phi) + k_{d,\phi}(\dot{\phi}_d - \dot{\phi}) \\ k_{p,\theta}(\theta_d - \theta) + k_{d,\theta}(\dot{\theta}_d - \dot{\theta}) \end{bmatrix} l$$

$$k_{p,\phi} = 4.5, k_{d,\phi} = 0.5, k_{p,\theta} = 4.5, k_{d,\theta} = 0.5, k_p = 7.5, k_d = 4.2$$

Impact of Wind Speed



Impact of Desired Vehicle Ground Speed



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Monte Carlo Method

- UTM requires parameter and uncertainty/error studies
- UTM uncertainties/errors are high-dimensional
- Monte Carlo method is independent of the problem dimension
- The rate of convergence of order is : $O(1/\sqrt{n})$
- Error percentage can be computed by:

$$E = \frac{100 z_c S_x}{\bar{x}\sqrt{n}}$$

- Monte Carlo is widely used in finance and engineering

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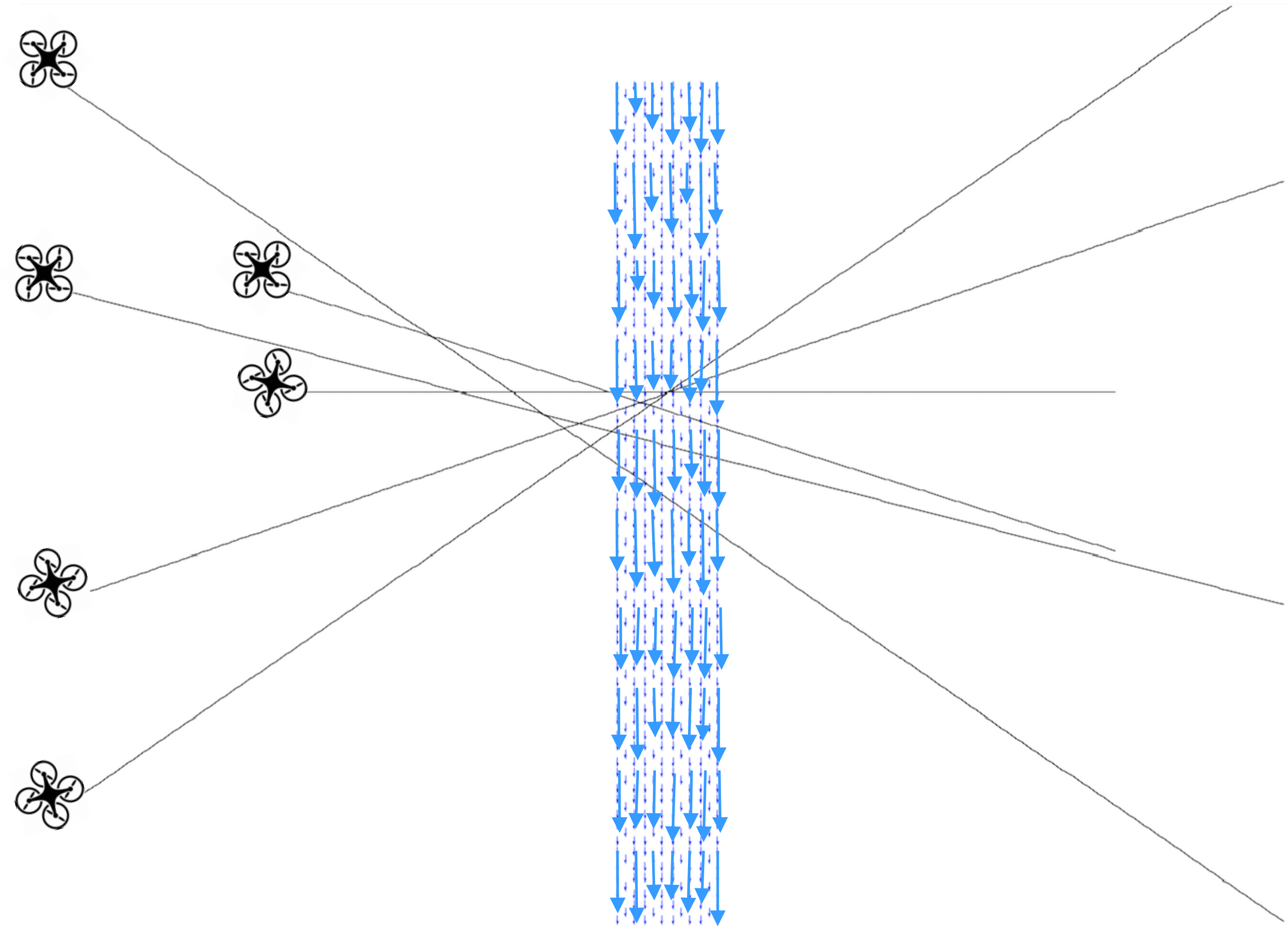
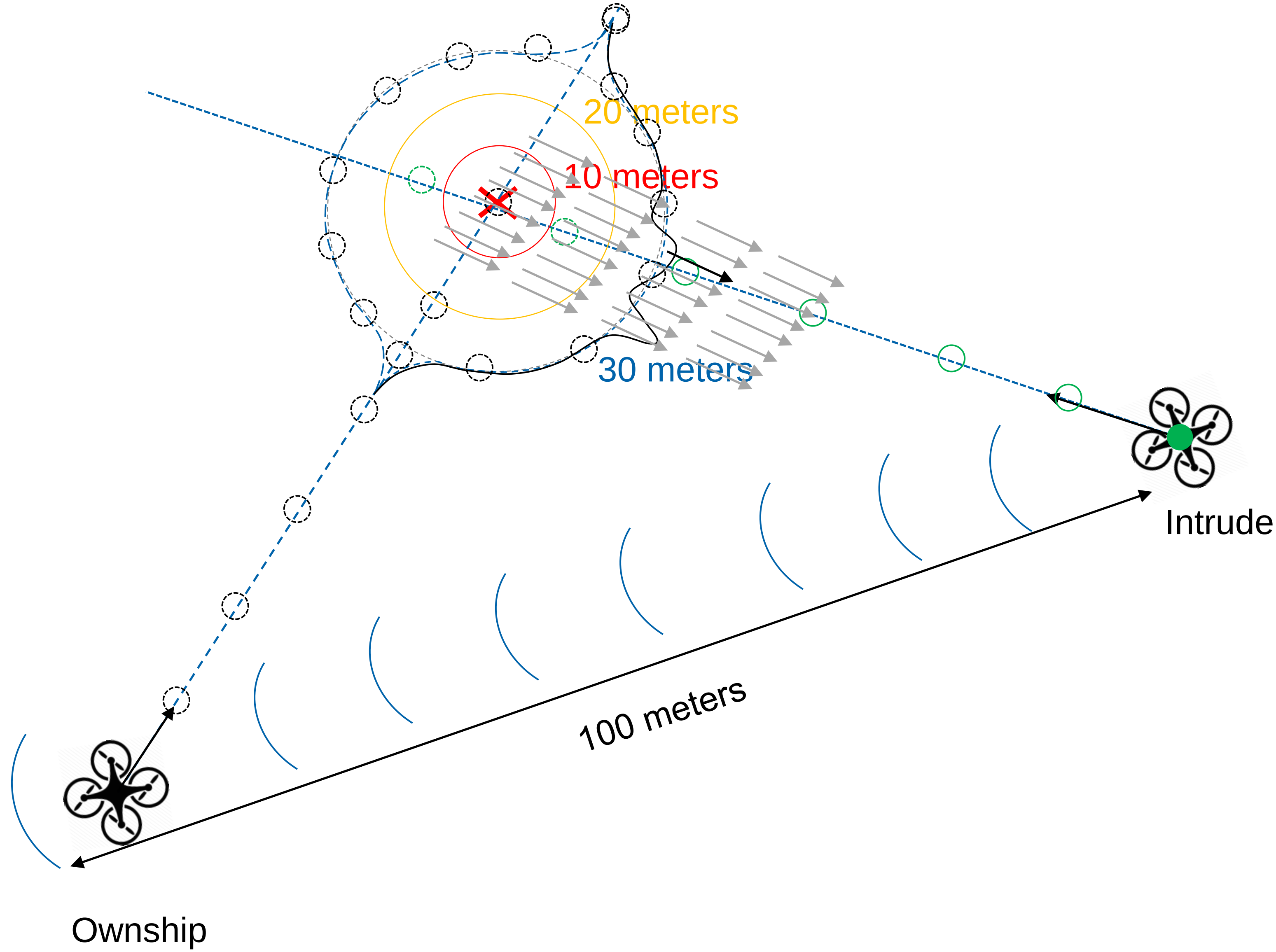
Scenario



- Six quadrotors with V_g= 5 m/s
- A rectangular north wind field with uncertainty

Setup



Experiment #1: Impact of Wind

Wind speed (m/s)		Avoidance maneuver	Loss of separation (probability)			Extra flight distance (m)			Extra flight time (s)		
mean	Std.		mean	Std.	Error(%)	mean	Std.	Error(%)	mean	Std.	Error(%)
0	0	Right turn	0	0	0	165.5	0.0	0.0	31.0	0.0	0.0
3	1	Right turn	0	0	0.0	168.8	3.6	0.12	31.0	0.03	0.01
5	2	Right turn	0.01	0.08	97.2	212.1	42.9	1.7	32.4	1.8	0.46

$$E = \frac{100 z_c S_x}{\bar{x}\sqrt{n}}$$

Experiment #2: Impact of Avoidance Maneuver

Wind speed (m/s)		Avoidance maneuver	Loss of separation (probability)			Extra flight distance (m)			Extra flight time (s)		
mean	Std.		mean	Std.	Error(%)	mean	Std.	Error(%)	mean	Std.	Error(%)
3	1	Right turn	0	0	0	168.8	3.6	0.17	31.0	0.03	0.01
3	1	Left turn	0.847	0.36	3.46	71.0	23.3	2.7	9.5	3.4	3.0
3	1	Hover	0.04	0.20	38.9	5.95	4.1	5.6	20.9	4.4	1.72

Summary

- Reviewed some existing simulations
- Identified UTM required attributes
- Conducted trajectory sensitivity analysis
- Conducted preliminary experiments using Monte Carlo

Future Work

- Implement the platform on the Cloud
- Incorporate and generalize more vehicle dynamic and control systems
- Implement and generalize more collision avoidance algorithms
- Implement onboard sensor and communication device models
- Environmental data (wind, temperature, etc.)
- Geographic Information System (GIS) data (terrain, population, etc)